

HEAT-RESISTANT CHROMIUM CARBIDE COATING
WITH A SILICATE BINDER

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FACILITY FORM 502	N66 33690	
	(ACCESSION NUMBER)	(HRU)
	14	1
	(PAGES)	(CODE)
	(NASA CR OR TMX OR AD NUMBER)	17
		(CATEGORY)

Translation of "Zharostoykoye pokrytiye iz karbida
khroma s silikatnoy svyazkoy".
Zashchita Metallov, Vol.1, No.6, pp.687-691, 1965.

GPO PRICE \$ _____

CFSTI PRICE(S) \$ _____

Hard copy (HC) \$ 1.00

Microfiche (MF) .50

ff 653 July 65

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON
JUNE 1966

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Investigation of the process of formation (at 1200 and 1250°C) and application to steel of a heat-resistant chromium carbide coating (84% Cr, 13.3% C) with 10, 15, 20, 30, and 50 wt.% of a low-alkaline borosilicate binder. The possibility of effective application of this coating to St 3 steel is demonstrated. The coating gives this steel good protection from oxidation in air for 200 hrs at temperatures to 1000°C; it resists thermal shocks and has adequate adhesion.

In recent years, great significance is being acquired by the problem of the development of heat-resistant protective coatings, associated with increasing the effective temperatures and the need for extending the service period of parts under operating conditions. In the development of heat-resistant coatings, use is made of refractory compounds, including MoSi_2 , SiC , Cr_3C_2 , CrB_2 , and others (Bibl.1 - 5). Such coatings are obtained on the surface of materials by various methods: by diffusion saturation of the surface, by deposition and by spraying (Bibl.6).

Effective refractory coatings of chromium carbide on steel were obtained by means of electrolytic chromium-plating, followed by carbide coating (Bibl.7), by gas-flame deposition of carbide cermets (Bibl.5) and also by layering, using

* Numbers in the margin indicate pagination in the original foreign text.

the method of cementing of composites made of chromium carbide with a binder (Bibl.4). The carbide coatings combine increased heat resistance with high wear and acid resistance.

In our work, we studied the conditions of formation of a chromium carbide coating with a silicate binder by the enameling process; certain properties of such a coating were investigated. By substituting a silicate binder for a metal one, we attempted to improve the heat resistance of a chromium carbide coating.

TABLE 1

COMPOSITION AND FORMATION TEMPERATURE OF CARBIDE COATINGS

Composition of Coating wt. %		Temperature of Coating Formation °C
Chromium Carbide	Binder	
50	50	1200
70	30	
80	20	
85	15	1250
90	10	

As binder, we used a relatively easily fusible and fairly inert (with respect to the steel) low-alkali borosilicate glass (Bibl.8). As original components of the coatings, we used finely divided glass powders and chromium carbide (84% Cr; 13.3% C_{tot}; 0.1% C_b). The technology of applying the coatings from powders by the enameling method has been described previously (Bibl.9). The annealing of the coating was done in an inert atmosphere (argon). As a base, we used steel specimens with dimensions of 40 × 20 × 4 mm. In all cases, the total thickness of the coating was 0.15 - 0.25 mm.

The formulas for the investigated composites and the temperatures of their welding to the steel are given in Table 1. An increase in the amount of binder

in the coating from 10 to 50% causes a decrease in the temperature of deposition of the coating by 40 - 50°C.

In the process of applying the coating, the borosilicate glass (binder) plays the role of the liquid phase in which the oxide films are dissolved from the carbide grains and from the steel surface. This results in an increase of the ability of the carbide particles to interact with themselves and with the steel, leading to the formation of a compact nonporous deposition of the coating, with good adherence to the steel.



Fig.1 Microstructure of Carbide Coating ($\times 500$)

The structure of the coating (Fig.1) is heterogeneous and includes at /688 least three phases: glass (black parts) and two carbide phases differing in their pickling ability in a 5% alcoholic solution of nitric acid. The glass was concentrated mainly in the upper layer of the coating, in the form of separate small blobs.

Humenik and Parikh (Bibl.10), in studying the microdistribution of phases in cermet systems from the viewpoint of the wettability of the solid phase, demonstrated that complete wettability of the solid phase (contact angle of wetting $\theta = 0$) leads to complete production of the liquid phase between the grains. At incomplete wetting ($90^\circ > \theta > 0^\circ$), an apparent grain growth of the solid phase is observed, explained chiefly by grain coalescence.

TABLE 2
FORMATION TEMPERATURE OF CARBIDE COATINGS
OF VARIOUS MATERIALS

Grade of Steel or Alloy	Temperature ($^\circ\text{C}$) of Coating Formation
St. 3	1200 - 1240
Kh12I20GZR, Kh18N9T	1240 - 1260
Kh175MBTYU, KhN70VMTYU	1260 - 1280

The contact angles of wetting of chromium carbide by borosilicate glass, measured by us in an argon atmosphere at 1000, 1100, and 1200 $^\circ$ respectively,

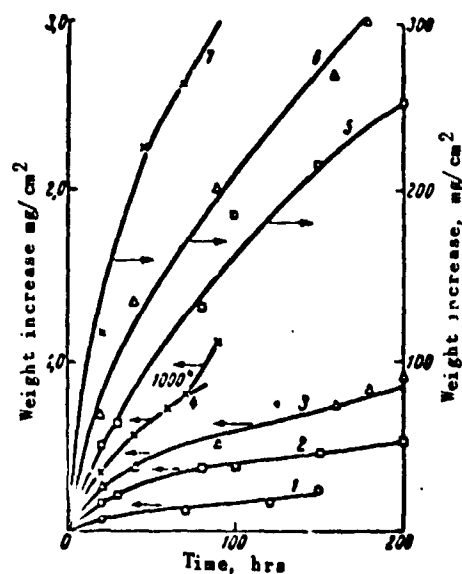


Fig.2 Oxidation Curves for St. 3 without Coating (1 - 4) and with Coating (5 - 7) in Air at Various Temperatures
1 - 800 $^\circ\text{C}$, 2 and 3 - 910 $^\circ\text{C}$, 5 and 6 - 950 $^\circ\text{C}$, 4 and 7 - 1000 $^\circ\text{C}$

are 78, 57, and 41°. Thus, in the formation of a chromium carbide and glass coating, incomplete wetting of the chromium carbide by the glass ($90^\circ > \theta > 0^\circ$) takes place, evidently leading to a coalescence of the carbide particles and to an agglomeration of the glass into separate small groups.

At a high binder content (40 - 50%) on the surface of the coating during 1689 deposition of the layer a solid film of glass is formed which poorly adheres to the carbide phase and shows a tendency to peel off on cooling of the specimen. At a low binder content (less than 20%), the melted glass does not form a continuous film but occurs in discrete islets in the surface layer, which show fair adherence obviously because of their lower stress, relative to the continuous film.

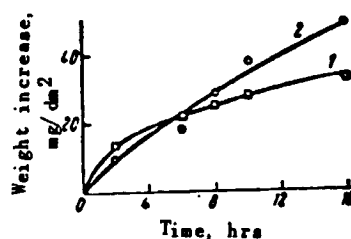


Fig.3 Oxidation Curves for St. 3 with Carbide Coating, in Air at 1000°C, Obtained by the Enameling Process (1) and According to Data (Bibl.7) of Electrolytic Chromium-Plating Followed by Carbide Coating (2)

For our further investigations, we selected a coating with 10% binder. A characteristic of carbide coatings with a silicate binder is the narrow temperature range at which the hard facing can be applied. A slight overheating during buildup of the surface leads to beading and pitting of the coating. Deposition of the coating to a large area is obtained by reducing the temperature and lengthening the annealing time. The temperature of formation of the coating is dependent on the nature of the base. It is evident from Table 2 that the described coating forms most readily on the grade St.3 steel and least readily

on the KhN70VMYTU alloy. The dependence of the temperature of formation of the coating on the type of base obviously can be attributed to the varying reactivity of the latter at the deposition temperature.

TABLE 3
EFFICIENCY OF OXIDATION PROTECTION OF St. 3 STEEL
BY A CARBIDE COATING

Material	Weight Increase (mg/cm ²) per 200 hrs at Temperatures (°C)			
	800	910	950	1000
St.3 without coating	-	250	310	260 ²
St.3 with coating	0.24 ¹	0.52	0.91	5.2

Duration of test: ¹⁾ 150 hrs; ²⁾ 70 hrs

For an evaluation of the properties of carbide coatings, tests were conducted on the prolonged thermal stability, heat resistance and impact strength. Thermal stability was determined after protracted holding of the coated specimens in an atmosphere of air under static conditions at temperatures of 800, 1690

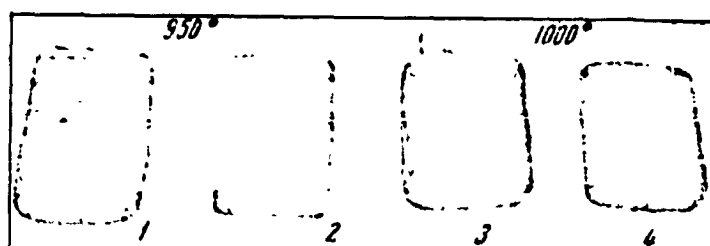


Fig.4 Outer View of Samples of St. 3 after Testing
for Thermal Stability
1, 3 - Unprotected samples; 2, 4 - Carbide coating applied

910, 950, and 1000°C in an electric furnace. The samples were withdrawn periodically, cooled and weighed. The results gained from testing St. 3 for prolonged thermal stability, shown in Table 3, indicate that the carbide coating effectively protects this steel from oxidation in air in the temperature range

800 - 1000° for a protracted time.

The oxidation curves for St. 3 with and without a coating are presented in Fig.2. At temperatures of 800, 910, and 950°C, a slight gain in weight of the protected samples over the test period was observed. However, at 1000°C after 70 hrs of oxidation, the weight of the samples started increasing abruptly owing to the appearance of local cracks in the coating. In spite of this, the coating continues to protect the steel from oxidation.

A comparison of data given elsewhere (Bibl.7) on the oxidation of steel coated by electrolytic chromium-plating followed by carbidizing treatment, with the results from our thermal stability tests (Fig.3) indicates that the corresponding oxidation curves evidently differ because of the varying nature of the oxide films that are forming.

TABLE 4
RESULTS OF HEAT RESISTANCE TESTS

Original Samples	Number of Thermal Cycles	
	Up to Appearance of Cracks along Ribs to Metal	Up to Appearance of Cracks on Plane to Metal
After application of coating	15 - 20	40 - 54
Coated and additionally processed under conditions: heating to 950°C for 15 min, holding 2 hrs, and cooling in a furnace under argon	10 - 15	25 - 43
Coated and additionally subjected to five-fold heat treatment under conditions: heating to 1050°C for 7 min, cooling for 3 min	10 - 15	28 - 38

The outer appearance of samples of St. 3 with and without coating, after thermal stability testing for 200 hrs is plotted in Fig.4. The unprotected

samples became coated with a layer of scale which peeled off in thick films, whereas the samples with the coating showed no sign of damage.

The heat resistance tests were conducted under the conditions: heating for 10 min to 900°C, cooling with compressed air to 20°C for 5 min. After each /697 five thermal cycles, the surface was inspected under a binocular microscope for the appearance of cracks. The test results (average data from three determinations) are presented in Table 4.

From this Table it is evident that the cracks appear initially along the ribs, i.e., in places where the stresses are maximum. We observed no appreciable increase or decrease in heat resistance by additional heat treatment, as occurs in the case of cermets from chromium-nickel carbides (Bibl.11).

The tests for impact strength were conducted in an impact machine of Novocherkassk design at the Polytechnical Institute. Up to an impact of 8 joules, the coating did not peel off and only a depression of 3 - 4 mm diameter formed at the point of impact. This demonstrates the excellent adhesion of the described coating to the steel base.

CONCLUSIONS

1. We demonstrated the basic feasibility of coating St. 3 steel with a protective coating of chromium carbide with a silicate binder, using the enamelling process.

2. The carbide coating effectively protects the St. 3 from oxidation in air for a prolonged time (200 hrs) at temperatures up to 1000°C, has satisfactory resistance to thermal shock, and possesses good adhesion to the base.

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Received
May 12, 1965

Translated for the National Aeronautics and Space Administration by the
O.W.Leibiger Research Laboratories, Inc.